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THE ENERGIES RELEASED IN THE REACTIONS
 $\text{Li}^7(p, \alpha)\text{He}^4$ AND $\text{Li}^6(d, \alpha)\text{He}^4$, AND THE MASSES
OF THE LIGHT ATOMS

A DISSERTATION SUBMITTED TO THE FACULTY
OF THE DIVISION OF THE PHYSICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY

DEPARTMENT OF PHYSICS

1939

By

NICHOLAS M. SMITH, JR.

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The Energies Released in the Reactions $\text{Li}^7(p, \alpha)\text{He}^4$ and $\text{Li}^6(d, \alpha)\text{He}^4$, and the Masses of the Light Atoms

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The energies of the alpha-particles arising from the reactions $\text{Li}^7(p, \alpha)\text{He}^4$ and $\text{Li}^6(d, \alpha)\text{He}^4$ have been measured by stopping the particles in a calibrated, variable pressure, air-filled absorption cell. The use of collodion windows on the cell instead of mica, the use of thin instead of thick targets, and the prevention of the formation of oil films on the targets, were improvements in technique over the older determinations of Oliphant, Kempton, and Rutherford. The energy release in the Li^7 disintegration was found to be 17.28 ± 0.03 Mev; that for the Li^6 , 22.20 ± 0.04 Mev. These new values are used, together with the energies of the beryllium-proton disintegrations measured with the electrostatic analyzer, to set up masses for the light atoms concerned. The following values are obtained: Li^6 , 6.01682 ± 0.00011 , Li^7 , 7.01784 ± 0.00009 , Be^8 , 8.00766 ± 0.00015 , Be^9 , 9.01486 ± 0.00013 .

INTRODUCTION

IN a recent paper Allison¹ set up a provisional table of masses of the light atoms from disintegration data. The energies of some of the reactions used in his paper are not known with an accuracy comparable to that of the others, which were obtained in this laboratory by electrostatic deflection of the disintegration particles. Inasmuch as it is the absolute and not the percentage error which is important in mass determinations, it is necessary to know all large Q values to high precision. The present paper is a report of experiments to determine more accurately the energy released in the reactions $\text{Li}^7(p, \alpha)\text{He}^4$ and $\text{Li}^6(d, \alpha)\text{He}^4$. This was done by a comparison of the α -particle ranges with that of natural particles in an absorption cell. The most accurate measurement of these energies made previously was by Oliphant, Kempton, and Rutherford,² whose experiment is, in essence, duplicated here. They obtained a Q value of $22.06 \pm .07$ Mev for the Li^6 reaction which Livingston and Bethe³ corrected to $22.07 \pm .07$, and $17.06 \pm .06$ Mev for the Li^7 reaction, similarly corrected to $17.13 \pm .06$. As in their experiment, the ranges here were compared with that of the shorter particles from $\text{Th C}'$.

APPARATUS

The high voltage apparatus used was the Cockcroft-Walton circuit previously described by Hatch.⁴ Positive ions were pulled by a tungsten probe from a low voltage capillary arc, so constructed that the ions had a path of only a few inches to traverse before receiving their first large acceleration. Magnetically separated beams of the order of ten microamperes of protons or deuterons were recorded as coming through the $\frac{1}{4}$ -inch collimating apertures.

Thin targets were prepared by heating a bead of lithium fluoride on a nickel wire in a flame and holding a polished nickel target button for two or three seconds in the red flame above the bead. A faint cloud of the fluoride could be observed on the button after evaporation. Also a thin target of Li^6 separated in a mass spectrograph by L. H. Rumbaugh was used, and the agreement of mean range as calculated from it with that from the fluoride targets furnished proof of the thinness of the latter. Thin $\text{Th C}'$ sources were made by collecting the active emanation from radiothorium on a charged nickel button. After each run with the lithium target, the $\text{Th C}'$ source was quickly substituted and a run taken immediately afterward. The intensity of the $\text{Th C}'$ source was such that about 750 counts per minute were obtained on the flat part of the number-pressure curve. The curve

¹ S. K. Allison, Phys. Rev. **55**, 624 (1939).

² M. L. E. Oliphant, A. E. Kempton, and Lord Rutherford, Proc. Roy. Soc. London **A149**, 406 (1935).

³ M. S. Livingston and H. A. Bethe, Rev. Mod. Phys. **9**, 309, 318 (1937).

⁴ G. T. Hatch, Phys. Rev. **54**, 165 (1938).

was taken with the pressure decreasing, and then repeated with the pressure increasing. The entire run could be completed in about 30 minutes, and during this time corrections for the decay of the source (effective half-life about 11 hours) were negligible. The Th C' source was heated in the target chamber to prevent any oil film developing on it from the diffusion pumps. The same heating technique⁴ was applied to the lithium fluoride and separated Li⁶ targets. Targets of lithium fluoride, or other alkali halides, will discolor under ionic bombardment. This discoloration, however, is not due to carbonization of oil films, but represents a change in the halide itself, which may be similar to the effect produced by x-rays on the halides. Clean metallic targets, bombarded in the same way as the halide targets, show no brown deposit provided they are heated up from our filaments before bombardment begins.

Figure 1 is a drawing to scale of the absorption cell, target, and ionization chamber. The disintegration products were observed at 90° from the bombarding beam. Aperture C was circular and 0.636 cm in diameter. Apertures A and B were 0.953 cm in diameter. The brass plates containing A and B were seated accurately against shoulders on the cylindrical body of the absorption cell. They were held in place by collars and sealed by packing glands. The method of construction insures that the length of the cell is independent of the tightness with which the screws are drawn up to make the seal. The length of the cell was so chosen that the working pressure was always greater than atmospheric. Perforated copper screens⁵ of transmission ratio 0.315 (ratio of open area to total area) covered apertures A and B as shown, and thin collodion films, of about 0.35 cm stopping power each, were placed on the high pressure sides of the screens. The low pressure side of the screen over B acted as the front plate of the ionization chamber. The rigid assembly consisting of the back plate and guard ring of the ionization chamber and first stage of the amplifier fitted snugly into the back of the cell as shown, and was held in firm mechanical contact by stretched rubber bands. It was found that this

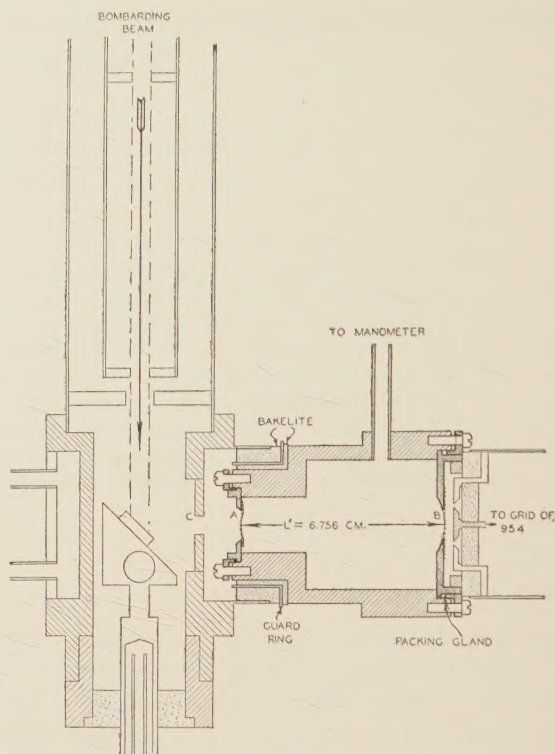


FIG. 1. The absorption cell, together with the target assembly and the ionization chamber.

was important to cut down amplifier noise arising from vibration. The depth of the chamber was 0.3 cm.

Air was admitted into the cell through a copper tube soldered into the side. The air was freed of moisture and carbon dioxide by passage through tubes of calcium chloride and sodium hydroxide. Its temperature was measured by a thermometer whose bulb rested on the cell. The pressure was measured in an open tube mercury manometer. A correction was made for the temperature of the mercury. A volume of several liters was placed on the line to stabilize the pressure. An accurate aneroid barometer measured atmospheric pressure. This was of use only for noting variations in pressure during a run. Such variations turned out to be negligible for most of the data.

In order to apply a voltage to the front plate of the ionization chamber, the entire absorption cell was raised to a potential of 216 volts by means of dry cells. The guard ring shown in the drawing served to keep leakage current from

⁵ R. B. Bowersox, Phys. Rev. **55**, 323 (1939).

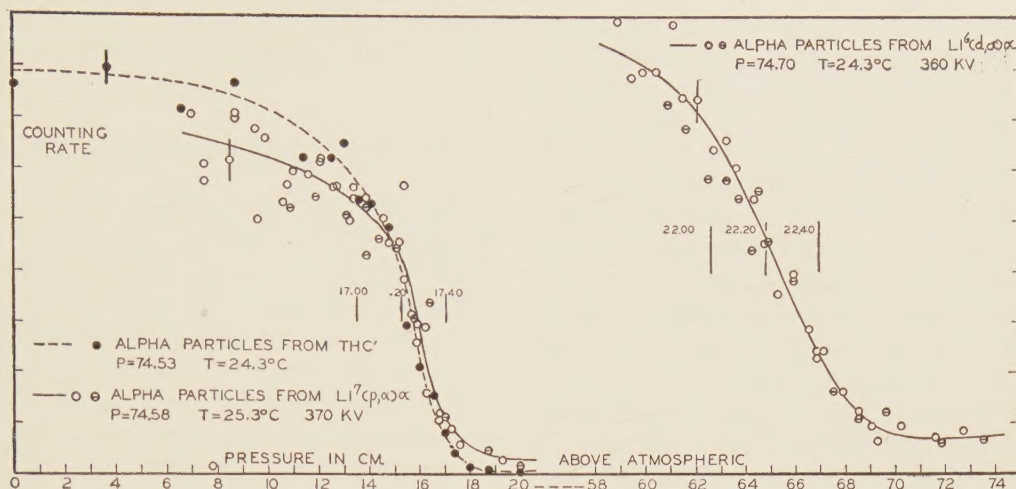


FIG. 2. A sample number-pressure curve for the natural α -particles from Th C' and the artificial α -particles from each of the reactions: ${}^7_3\text{Li}(p, \alpha){}^4_2\text{He}$ and ${}^6_3\text{Li}(d, \alpha){}^4_2\text{He}$. The excess pressure corresponding to mean range for the Th C' data was found by differentiation to be 15.7 cm Hg, for the Li^7 reaction 16.0 cm Hg, and for the Li^6 reaction 65.0 cm Hg. The vertical lines labeled 17.00, .20, 17.40 and those marked 22.00, 22.20, etc., refer to points where the maximum slope of the artificial α -particle curves should appear in order to give the indicated Q for the respective reactions.

being read by the beam galvanometer. The first stage of the amplifier was an RCA 954 Acorn type pentode. The tube is of small size, is not microphonic, and has a low input capacitance. The latter was further minimized by placing the tube in close proximity to the ionization chamber. A potential of about five volts was used on the heater and $22\frac{1}{2}$ and 45 volts on screen and plate, respectively. The signal-to-noise ratio of the amplifier for alpha-particles was about 50 as measured on the oscilloscope, while the ratio of the biases on the scaling circuit which would just count alpha-particles to that which would just count background was 5. The scaling circuit was operated at a bias somewhat more negative than that at which background could be counted. The author estimates that it would count alpha-particles of residual range greater than 0.2 mm. This conclusion is based on an examination of the specific ionization curves of Holloway and Livingston.⁶ At this bias the protons from deuterons on Li^6 were counted with the alpha-particles. Because of the long range of the protons, however, their presence made no difference in the shape of the alpha-particle curve. The bias for each lithium run was

the same as for its Th C' comparison. Sample curves are shown in Fig. 2.

THE COMPARISON OF RANGES WITH THE ABSORPTION CELL

The alpha-particle range *vs.* energy curves of Livingston and Bethe³ apply to a pressure of 760 mm and a temperature of 15°C. We have therefore adopted these conditions as standard and reduced our readings to them. With this in mind, the action of the absorption cell in stopping a group of alpha-particles may be represented as follows:

$$R = L \frac{p + P}{76} \frac{288}{T} + C. \quad (1)$$

In this expression R is the mean range in centimeters of the particles at 76 cm Hg pressure and 15°C; L is the length of path in the air of the absorption cell; p is the critical excess pressure in cm Hg corresponding to the mean range; P is the atmospheric pressure; T is the temperature in °K at which p was determined; and C is a constant of the absorption cell.

The constant C includes the air equivalent of the windows and the necessary penetration into the ionization chamber for registration as an alpha-particle. Since only light atoms occurred

⁶ M. G. Holloway and M. S. Livingston, Phys. Rev. 54, 18 (1938).

in the collision of the films on the windows, the effect of the change of stopping power relative to that of air with energy of the alpha-particles is negligible. The air equivalent of C was approximately 0.8 cm.

The abscissa of the number *vs.* pressure curve at which the slope was a maximum was used for the computation of the relative mean range.

The absolute temperature T at which a curve was taken on artificial alpha-particles was usually the same as that of the comparison run on the Th C' particles (taken immediately afterward). In the few cases in which a significant temperature change occurred between a run and its comparison, $\Delta(p+P)$ has been corrected before entry in the tables. We can thus assume T a constant for a run and its natural alpha-particle comparison. If ΔR is the difference between the mean ranges of two different homogeneous groups of alpha-particles, we can write

$$\Delta R = \frac{L}{T} \frac{288}{76} \Delta(p+P), \quad (2)$$

where $\Delta(p+P)$ is the increase in the total pressure in the absorption cell required to stop the artificial group.

THE $\text{Li}^7(p, \alpha)\text{He}^4$ REACTION

Since the energy of the alpha-particles released in the artificial disintegration of Li^7 is almost exactly equal to that of the natural Th C' particles, we may write

$$E_\alpha = E_n + \Delta R(dE/dR), \quad (3)$$

where E_α is the energy of the artificial particles, E_n that of the Th C' particles, and dE/dR the slope of the range-energy curve in the region of 8.7 Mev. This slope is 0.64 Mev/cm. For the above reaction the energy release Q is given (at 90° to the bombarding beam of protons) by

$$Q = 2E_\alpha - E_p(M_\alpha - M_p)/M_\alpha,$$

where the subscripts α and p refer to alpha-particles and protons, respectively, M 's are masses, and E 's, energies. On substitution of numerical values, and using Eqs. (2) and (3), we obtain

$$Q = 2E_n - 0.748E_p + k\Delta(p+P), \quad (4)$$

where

$$k = 2(dE/dR) \frac{L}{T} \frac{288}{76}.$$

THE $\text{Li}^6(d, \alpha)\text{He}^4$ REACTION

The disintegration particles from the Li^6 -deuteron reaction, on the other hand, are so widely different in energy from those of Th C' that one cannot assume the range-energy relation to be linear in the region. It is necessary to calculate the range of the artificial particles explicitly and then take the energy corresponding to this range as determined from the range-energy curves of Livingston and Bethe.³ We may write

$$R_\alpha = R_n + k'(p+P), \quad (5)$$

where $k' = (L/T)(288/76)$.

The energy release Q in this reaction at 90° to the deuteron beam is given by

$$Q = 2E_\alpha - 0.4968E_d. \quad (6)$$

CORRECTIONS

Corrections for various sources of error must be estimated and applied.

(a) Window bulge

The pressure of the air in the absorption cell caused the thin copper screens in A and B to bulge outward slightly. The sagittae of the bulges of the windows were measured by means of a dial indicator. The position of contact with the copper screen of the movable ball point of the indicator was determined electrically. It was first shown that the bulges were fully developed at the pressure required to stop Th C' particles; that is, no significant further bulge occurred when the pressure was raised to the critical point for the Li^6 particles. The absolute bulge, S_a , of window A was 0.063 cm, and S_b was 0.051 cm. The extreme distance in the cell between the tips of the bulges was 6.813 cm. Assuming that the bulges were in the form of spherical caps, a mean bulge was calculated such that half the particles traversed paths longer than this mean, and half shorter. From the sagitta formula it is easily shown that this mean is just half the total bulge. Therefore the

effective length is $6.813 - \frac{1}{2}(S_a + S_b)$ or 6.756 ± 0.001 cm, and this value was used in the formulae.

(b) Temperature of the mercury manometer

The correction of the density of the mercury in the open end manometer was significant in the Li^6 reaction. It resulted in lowering $\Delta(p+P)$ by about 0.5 percent. The correction has been applied to k' in Table II.

(c) Obliquity

The geometrical effect due to finite size of the apertures limiting the alpha-particle beam results in a shortening of the observed ranges. This is a correction to be made to $\Delta(p+P)$, and is 0.13 percent as calculated from the formula of Livingston and Bethe.⁷

(d) Variation of bombarding voltage

During some runs the bombarding voltage varied by as much as 5 percent. In such cases, the observed number of particles was corrected for a change of yield with voltage. In the Li^7 reaction, the data of Haworth and King⁸ were used for this purpose. However on the runs requiring correction for this effect, the scattering of the points was usually great for other reasons, and the runs were given low weight in averaging for the final result.

(e) Deviation of air from Boyle's law

The deviation from Boyle's law at the pressure of the Li^6 cut-off was computed from van der Waals' equation to require a correction of 0.10 percent. This correction is in the same direction as the obliquity correction, and both were applied to k' in Table II.

(f) Straggling

The most convenient aspect of the number-pressure curves to use in discussing the straggling is s , the difference between mean and extrapolated range, expressed in cm and reduced to

76 cm and 15°C . The three principal sources of straggling in these experiments were (1) range straggling s_1 , due to the statistical nature of the loss of energy by the alpha-particle, (2) noise straggling s_2 , due to the fact that the alpha-particle pulses coming from the amplifier were superimposed on a variable noise background, and (3) angle straggling s_3 , due to the fact that the energy of alpha-particles from artificial disintegrations is a function of the angle of emission with respect to the bombarding beam.

The Th C' curve of Fig. 2 should contain only range and noise straggling. The value of $\Delta(p+P)$ corresponding to the difference between mean and extrapolated ranges on this curve is $16.8 - 15.7 = 1.1$ cm, which, reduced by Eq. (2), gives $s_{12}(\text{obs.}) = 0.095$ cm. Other investigators have found⁹ that for Th C' alpha-particles s_1 is 1.08 percent of the 8.53 cm mean range or 0.092 cm. The agreement is good and shows that the noise straggling for the run was small compared to the range straggling.

If the aperture is sufficiently small, the angle straggling, present in the artificial disintegration curves, may be considered as superimposing a further Gaussian distribution of ranges on the range and noise straggling. The following considerations show that the aperture was sufficiently small for this method of considering the angle straggling.

From Fig. 1, it may be shown that the maximum angle that any alpha-particle can make with the axis of the absorption cell and be registered in the ionization chamber is about $4^\circ 30'$. Livingston and Bethe define the aperture angle of two circular openings of radius a , situated b cm apart, as a/b . This is half the maximum possible angular deviation; therefore in their sense our aperture angle was $2^\circ 15'$. A disintegration particle making an angle less than 90° with the bombarding beam will have energy greater than a particle leaving at exactly 90° , but must traverse more absorbing material to reach the ionization chamber. Thus there is a certain angle δ_0 , measured from the forward direction of the bombarding beam, at which the projection of the range on the axis of the absorption cell

⁷ M. S. Livingston and H. A. Bethe, reference 3, Eq. (778a), p. 280.

⁸ L. J. Haworth and L. D. P. King, Phys. Rev. **54**, 38 (1938).

⁹ M. S. Livingston and H. A. Bethe, reference 3, Fig. 37, p. 285.

is a maximum. Livingston and Bethe¹⁰ show that δ_0 is given by

$$\cos \delta_0 = n \frac{(M_1 M_2)^{\frac{1}{2}}}{M} \left(\frac{E_1}{E_2} \right)^{\frac{1}{2}},$$

where n is the effective exponent of the velocity in the range *vs.* velocity curve at the energy of the emitted particle at 90° ; M_1 , M_2 , M are the masses of the bombarding particle, disintegration particle, and intermediate nucleus, respectively; E_1 , E_2 are the energies of the bombarding and disintegration particles.

For the Li^7 reaction we use $n=3.26$, $E_1=0.35$ Mev, $E_2=8.7$ Mev, and obtain $\cos \delta_0=0.16$, $\delta_0=80^\circ$. For the Li^6 reaction, $n=3.33$, $E_1=0.36$ Mev, $E_2=11.1$ Mev, so that $\delta_0=77^\circ$. These represent deviations from the axis of the absorption cell of 10° and 13° , respectively. Since our aperture is small compared to this, the geometry is "good."

The combined straggling s_{13} , due to range and angle straggling, may be found from

$$s_{13} = (s_1^2 + \gamma^2)^{\frac{1}{2}}.$$

γ may be found¹¹ as a fraction of the mean range from

$$\frac{\gamma}{R} = \frac{a}{b} n \frac{(M_1 M_2)^{\frac{1}{2}}}{M} \left(\frac{E_1}{E_2} \right)^{\frac{1}{2}},$$

where a/b is the aperture angle in radians and the other symbols have their previous significance. a/b for our experiments is taken as 0.05. For the Li^7 reaction we get $\gamma/R=0.8$ percent, while for the Li^6 reaction γ/R is 1.0 percent. Since s_1 for the Li^6 reaction is 1.05 percent of the mean range, we obtain

$s_{13}=1.4$ percent which corresponds to 0.115 cm for Li^7

$s_{13}=1.5$ percent which corresponds to 0.191 cm for Li^6

with 12.8 cm as the mean range of the latter reaction.

The observed curve for the Li^7 disintegration particles in Fig. 2 shows an s value very close

to that of the Th C' comparison curve, and thus the observed s is slightly smaller than the predicted s_{13} . Agreement is, however, probably within experimental error.

The observed curve for the Li^6 disintegration in Fig. 2 shows $s_{13}(\text{obs.})=69.0-65.0=4.0$ cm pressure, which reduced by Eq. (2) gives 0.34 cm linear difference. This value is much larger than the s_{13} of 0.19 cm predicted above. The various curves for Li^6 obtained in the course of the work do not all agree with that of Fig. 2 in this respect, however. In the curve taken for trial 4 of Table II, the slope was steeper and from this curve we obtained $s=0.17$ cm, in agreement with the predicted s_{13} . *It is important to note that this change of observed s was not accompanied by any change in the excess pressure for maximum slope, that is, the mean range pressure.* The critical value of p for trial 2 of Table II was 65.0 cm; that of trial 4 was 64.8 cm.

We may attribute this change in observed s to the varying contribution from noise straggling. In general, the noise was more pronounced in the artificial disintegration experiments than in the Th C' runs. This was due to the vibration from the belt-driven generator supplying power for the low voltage arc, from ripple in the high voltage coming down the bombarding beam and being picked up, etc. We may assume that conditions were fairly quiet in the Li^7 run of Fig. 2 and the Li^6 run of trial 4, Table II, and relatively noisy in the Li^6 curve of Fig. 2.

In conclusion, we may state that the amounts of straggling observed on our curves are not incompatible with those to be expected, and the straggling is of a symmetrical nature that will not change the location of the mean range pressure.

(g) Thickness of target

We have not made any correction for target thickness, but have assumed our targets to be thin. There is evidence for this in our experiments, aside from the method of preparation. The target of Li^6 , made by Rumbaugh in a mass spectrograph, must certainly be considered as thin. The agreement of the mean range pressure observed from this target (trial 1 in Table II) with that from our volatilized LiF targets is strong evidence for the thinness of the latter.

¹⁰ M. S. Livingston and H. A. Bethe, reference 3, Eq. (772), p. 278.

¹¹ M. S. Livingston and H. A. Bethe, reference 3, Eq. (777), p. 280.

The agreement in slope between the Li^7 and $\text{Th C}'$ curves of Fig. 2 is auxiliary, but not so conclusive, evidence, since the slopes may be affected by varying amplifier noise.

THE ENERGY OF THE $\text{Th C}'$ ALPHA-PARTICLES

Briggs' latest value for the energy of the principal group of alpha-particles from $\text{Th C}'$ was used. He obtained $E_\alpha = 8.7759 \pm 0.0009$ Mev.¹² The quantity $8.776 \pm .001$ Mev used in these calculations is unaffected by correction for new values of e/M for helium. According to Holloway and Livingston⁵ this energy corresponds to a mean range of $8.570 \pm .007$ cm. On the range-energy curve published by Livingston and Bethe in 1937, on the other hand, this corresponds to a mean range of 8.530 cm. (The 1938 curve contains only values below 8.00 Mev.) However, one is concerned here only with an energy difference corresponding to a given range difference, so that if the whole range curve is displaced slightly, no error results. The value of dE/dR obtained from this curve for the Li^7 reaction was 0.064 Mev/mm.

RESULTS

One set of data for each of the two reactions is plotted in Fig. 2. On these curves the excess pressure corresponding to the mean range for the $\text{Th C}'$ data was found by differentiation to be 15.7 cm Hg, for the Li^7 reaction 16.0 cm, and for the Li^6 reaction 65.0 cm Hg. The point just above the 8-cm mark on the abscissae is a point taken during a run on Li^7 when the bombarding beam of protons was thrown off the target by reversing the magnetic field. This experiment showed that the target holder was not contami-

nated with natural radioactivity from $\text{Th C}'$ targets which had frequently been attached to it, and thus that all the alpha-particles being counted actually came from the disintegration of Li^7 . On both artificial disintegration curves the points in which the circle is traversed with a bar were taken after the target had been bombarded continuously by the beam for over an hour. They show that the LiF was not driven off the target by the action of the beam. The vertical lines labeled 17.00, .20, 17.40, and those marked 22.00, etc., refer to points where the maximum slope of the artificial alpha-particle curves should appear in order to give the indicated Q for the respective reactions. The data for the Li^7 reaction are summarized in Table I, and for the Li^6 reaction in Table II. The discrepancies given are average deviations. The vertical lines through points on the curves of Fig. 2 have a length $2M^{\frac{1}{2}}$ where M is the actual number of counts.

These results may be used, in connection with the energies evolved in the beryllium-proton reactions,¹³ to compute the masses of Li^6 , Li^7 , Be^8 , Be^9 in terms of H^1 , D^2 , He^4 . We take the following masses and reaction energies as basic to our calculations.

	$\text{H}^1 = 1.00813 \pm 0.00002$,
	$\text{D}^2 = 2.01473 \pm 0.00006$,
	$\text{He}^4 = 4.00386 \pm 0.00006$,
$\text{Li}^6(d, \alpha)\text{He}^4$	$Q = 22.20 \pm 0.04$ Mev or 23.83 ± 0.04 mMU,
$\text{Li}^7(p, \alpha)\text{He}^4$	$Q = 17.28 \pm 0.03$ Mev or 18.55 ± 0.03 mMU,
$\text{Be}^9(p, \alpha)\text{Li}^6$	$Q = 2.152 \pm 0.04$ Mev or 2.311 ± 0.04 mMU,
$\text{Be}^9(p, d)\text{Be}^8$	$Q = 0.557 \pm 0.006$ Mev or 0.598 ± 0.006 mMU.

Using these values, we obtain

Li^6	6.01682 ± 0.00011 ,
Li^7	7.01814 ± 0.00009 ,
Be^8	8.00766 ± 0.00015 ,
Be^9	9.01486 ± 0.00013 .

It is believed that these masses are the most reliable values available at present.

TABLE I. The $\text{Li}^7(p, \alpha)\text{He}^4$ reaction. Calculation according to Eq. (4).

Trial	k (Mev)/(cm Hg)	$\Delta(p+P)$ cm Hg	E_p Mev	Q Mev	Weight
1	0.1114	-0.69	0.325	17.23	2
2	0.1109	0.00	0.348	17.25	8
(Fig. 2)					
3	0.1100	0.22	0.366	17.31	1
4	0.1100	0.35	0.372	17.30	10
Weighted Average			17.28 ± 0.03 Mev.		
Equivalent Milli-Mass Units			18.55 ± 0.03		

¹² G. H. Briggs, Proc. Roy. Soc. **A157**, 183 (1936).

¹³ S. K. Allison, L. S. Skaggs, and N. M. Smith, Jr., Phys. Rev. **54**, 171 (1938). L. S. Skaggs, Phys. Rev. **56**, 24 (1939).

TABLE II. The $\text{Li}^6(d, \alpha)\text{He}^4$ reaction. Calculation according to Eqs. (5) and (6). Range of Th C' alpha-particle 8.530 cm.

Trial	Target	k' corrected	$\Delta(p+P)$ (cm)	$k'\Delta(p+P)$ (cm)	R_α (cm)	E_α (Mev)	E_p (Mev)	Q (Mev)	Weight
1	Separated Li^6	0.0856	49.8	4.26	12.79	11.21	.350	22.24	3
2	Thin LiF	0.0856	49.7	4.25	12.78	11.20	.358	22.23	10
(Fig. 2) 3	Thin LiF	0.0849	48.8	4.14	12.68	11.14	.322	22.12	1
4	Thin LiF	0.0856	49.1	4.20	12.73	11.17	.324	22.18	10
Weighted Average					22.20 ± 0.04 Mev.				
Equivalent Milli-Mass Units					23.83 ± 0.04				

DISCUSSION

The Q values obtained in this work for the disintegrations of the lithium isotopes are both higher than the previous values found by Oliphant, Kempton, and Rutherford (17.28 *vs.* 17.06 and 22.20 *vs.* 22.06). Perhaps the most significant difference between the present work and that of the Cavendish investigators was the use of thin targets with precautions to prevent films forming over them. Both of these precautions, if they produced any effects at all, would tend to give higher mean ranges such as we have observed.

Barkas¹⁴ has recently published a set of masses of the lighter elements in which the masses comparable with our list were communicated to him by Professor H. A. Bethe. The masses to be compared with ours are:

H^1	1.00812 ± 0.00002 ,
D^2	2.01472 ± 0.00002 ,
He^4	4.00388 ± 0.00007 ,
Li^6	6.01690 ± 0.00020 ,
Li^7	7.01804 ± 0.00020 ,
Be^8	8.00777 ± 0.00020 ,
Be^9	9.01497 ± 0.00025 .

This set agrees with ours within the uncertainties listed. Bethe* has re-interpreted the old result of Oliphant, Kempton, and Rutherford on the energy release in the reaction $\text{Li}^6(d, \alpha)\text{He}^4$ and raised their value of 22.06 Mev to 22.21 Mev. This revision receives a remarkable confirmation in our result of 22.20 Mev. The set of values recently published by Allison¹ were greatly de-

pendent on the energy release assumed for this reaction, and were based on the 22.06 Mev value, which now seems definitely too low. The adoption of the higher value raises the mass of Be^8 until the uncertainty assigned to it overlaps twice the mass of the alpha-particle. Thus the question of the stability or instability of Be^8 is left undecided by the table. In a previous publication from our laboratory¹⁵ we stated that Be^8 is stable by as much as 300,000 volts. With the revised values of the data used to supplement our results with the electrostatic analyzer, it is now seen that no such definite statement is compatible with the present accuracy of the mass values.

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¹⁴ W. H. Barkas, Phys. Rev. **55**, 691 (1939).

* H. A. Bethe, private communication.

¹⁵ S. K. Allison, E. R. Graves, L. S. Skaggs, N. M. Smith, Jr., Phys. Rev. **55**, 107 (1939).

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